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LAND MANAGEMENT, WATER USE AND SALINITY PREVENTION

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Abstract: Agriculture in southern Australia which developed after clearing of native vegetation has allowed more water to drain through the profile leading to secondary salinity. The northern slopes region of Victoria is used as an example to illustrate the importance of the interaction between soils, climate and land use, particularly in the winter months when precipitation is usually greater than potential evaporation. The evaporation from different types of plants is discussed in relation to the hydrological significance of this excess of precipitation.

Land management to control water moving to the watertable is based on the manipulation of the species grown, particularly in relation to root growth, and some suggested strategies are given. If instead of replacing the native forest species which are deep rooting with wheat, they are replaced by agricultural species with appropriate root characteristics (e.g. lupins and lucerne) then it is suggested the water percolating to the watertable will be lessened and soil salinity reduced or prevented.

Secondary salinity in dryland areas of southern Australia has occurred following the removal of native vegetation and its replacement by agricultural species. These species transpire less water than the original vegetation resulting in greater drainage through the root zone. This drainage leads to rising levels of the water table and, in many cases, soil salting occurs as a consequence. Agricultural plants appear to have the capacity to use the volume of water escaping beyond the root zone (Peck 1977).

In the groundwater intake zone a wide range of climate, soil, geomorphology, land use, and land management occur and the quantity of water reaching the watertable is influenced by all of these factors. This paper discusses a simplistic hydrological model, the water use of native vegetation and introduced species and then deals with the potential for changing water use patterns of agriculturally important species on the duplex soils of north central Victoria, with a view to reducing through drainage.

WATER BALANCE

Where rainfall is the sole source of water, input (P) is equal to the output ($Ea+R+D$) plus storage (S),

that is $$P=Ea+R+D+S$$

P = rainfall
Ea = actual evapotranspiration
R = runoff
D = drainage
S = change in soil water content.

Applying this to the dryland farming areas of north central Victoria, manipulation of D can only be achieved by adjusting Ea. Runoff and drainage will increase as soil water content increases and there appears to be little opportunity for decreasing D by increasing R. Over a number of years S is zero.

North of the Great Divide in Victoria, potential evaporation (Eo) generally decreases from the north and west to the east and south and corresponds to increasing rainfall so that in the south and east of Victoria, particularly along the divide, winter rainfall can be very much greater than Eo (potential evaporation) while in the north, average winter rainfall approximately equals Eo (Table 1). There is also a great deal of variation in rainfall from year to year. The difference between recorded rainfall and average potential evaporation for Rochester is shown in Table 2. For the 39 year period from 1941 to 1979, winter rainfall exceeded mean, winter, potential evaporation in 17 years and in 1973, the wettest winter for this period, rainfall exceeded potential evaporation by 115 mm. The level of groundwater rose substantially in 1973 (Trewhella & Webster 1978) in the irrigation areas to the north of Rochester, the rise being attributed to the very high rainfall in that year.

A daily water balance model (Arch *et al.* 1981) was used to simulate a fallow-wheat-pasture rotation for conditions likely to occur at Diggora (10 km from Rochester). This model predicted that for the period 1941-79, 21, 22, 19 and 10% of total drainage occurred in the years 1956, 73, 74 and 55 respectively. The actual drainage for these years may have been greater than the model predicted as in these very wet years, crops were often not sown, failed or were severely restricted by disease. The excess of rainfall over average potential evapotranspiration (Et), where Et takes fractional values of Eo (1.0, 0.75, 0.5, 0.25), in high, medium and low rainfall years is given in Table 2.

In 1981, another wet year, substantial quantities of water drained through the profile of agricultural catchments but little water drained through forested catchments (P. Dyson, pers. comm.). It appears that native vegetation is able to minimise drainage even in very wet years. Guthrie *et al.* (1978), working at Stewarts Creek in a wet area, but on a northern aspect of the Divide, give figures which indicate that Ea for an open forest of *Eucalyptus obliqua* and *E. radiata* is 800 mm per year.

TABLE 1
EXCESS OF RAINFALL OVER POTENTIAL EVAPORATION (mm) IN NORTHERN VICTORIA
Eo was measured using a Class "A" Pan at Rutherglen and Australian Standard Pan near Maryborough and Rochester

Station	Autumn	Winter	Spring	Summer
Rochester (north)	−182	7	−277	−530
Maryborough (southwest)	−162	47	−125	−466
Rutherglen (northeast)	−190	81	−112	−613

Holmes and Colville (1968), working on the Gambier Plain of South Australia showed that recharge of groundwater in the period 1960 to 1965 was 63 mm per year beneath grass whereas there was no recharge beneath a forest of *Pinus radiata*. This ranged from a low of 25 mm in 1961 to a high of 134 mm in 1964 when rainfall (June to December) was 386 and 748 mm respectively.

When native vegetation, including forest, is replaced by pastures and crops, *Ea* is generally reduced, leading to increases in drainage to the groundwater. However, some agricultural species have little impact on the hydrological balance. There appears to be a similarity in the growth habit and root morphology of lucerne and native heath when growing on sandy soils in the upper southeast of South Australia leading to similar water use patterns (Holmes 1960). This suggests that a knowledge of the water relationships of vegetation native to an area could provide guidance as to the most important attributes necessary for agriculturally important species to maximise evapotranspiration.

HYDROLOGICAL ASPECTS OF NATIVE VEGETATION

Although it is well known that little water escapes the root zone of the native vegetation to enter the groundwater, there appears to be little information on the mechanisms adopted by native vegetation to achieve this, although year round evapotranspiration usually occurs. Field measurements in the jarrah (*E. marginata*) forests of the Darling Range in Western Australia (Carbon *et al.* 1980) showed that these forests have a root system extending to 19 m although root systems may be deeper in other areas, to 50-60 m (as observed in the field). These workers did not present the water holding characteristics of the soil but it can be reasonably expected that the soil in the root zone can potentially store at least 2000 mm of water to 19 m, the quantity of water that would have to be added to the soil, when the soil was as dry as the lower limit to which plants might extract water, to raise its water content to a point where substantial drainage would occur. In the region of Western Australia, where this work was undertaken, annual average rainfall is less than 1200 mm or approximately one half of the potential water storage, so under this native hardwood forest, drainage is unlikely to occur.

The root depth of the forest and the water holding capacity of the soil determine the amount of water that can be stored for plant use. The potential rate at which that water can be utilised is determined by the atmospheric demand (*Eo*) and the water content of the soil. The actual rate is largely controlled by the hydraulic conductivity and water potential of the soil, the density of roots and plant factors including susceptibility to wilt.

A greater density of roots is required for a plant to be able to meet demand on a day of high evaporation than on a day of low evaporation. Similarly a greater density of roots is required as the soil water content decreases to meet this evaporation demand. In the jarrah forest, reported by Carbon *et al.* (1980) there were sufficient roots to supply water at a rate equivalent to the highest daily evaporative demand likely in summer even when the soil water content approached the lower limit that the trees could extract.

During a 14 month period the evapotranspiration from a single pine tree (introduced species) and associated pasture accounted for all rainfall at a location in a medium rainfall region (900 mm) east of Perth (Greenwood *et al.* 1981). No water drained beyond the root zone, confirming the earlier work of Holmes and Colville (1968). Two-thirds of the yearly evapotranspiration occurred between July and December and one-third between January and June. The pine tree transpired (*Ea*) at a rate equivalent to evaporative demand (*Eo*) when adequate water was present and the ratio of *Ea* to *Eo* decreased as soil water content decreased. This is similar to the performance of other perennials (Willatt 1971) and annuals (Anderson 1980). There appeared to be no mechanism in the pine tree to delay water use or conserve water.

Native forests appear to have evolved mechanisms that also allow high rates of transpiration even when the leaves are severely stressed (Sinclair 1980, Ladiges 1974) and yet these plants recover easily when water stress is relieved (Ladiges 1974). The extensive root systems of native forests create a large volume for storage of water and allow extraction of this water to occur rapidly even under conditions that would stress agricultural species (Sinclair 1980). In dry environments, where annual potential evaporation is very much greater than annual rainfall and where annual rainfall may vary a great deal, it is this ability of native vegetation to create an extensive water storage zone rather than the perennial nature of their growth that allows the forest to minimise or prevent drainage.

TABLE 2
EXCESS OF WINTER RAINFALL OVER POTENTIAL EVAPOTRANSPIRATION
Ranking Et at 4 levels for the years 1941-1979 at Rochester, where Eo = 125 mm

			Rain – Et(mm)			
Rank		Rain (mm)	Et = Eo	Et = 0.75Eo	Et = 0.5Eo	Et = 0.25Eo
1	Wettest winter 1973	240	115	146	177	209
10		153	28	59	91	122
20		121	−5	27	60	89
30		92	−34	−2	29	61
39	Driest winter 1944	29	−96	−64	−34	−2

Rainfall data supplied by Bureau of Meteorology.
Evaporation data supplied Tatura Irrigation Research Institute
(average evaporation 1941-1978)

THE POTENTIAL FOR INCREASING WATER USE OF AGRICULTURAL SPECIES BY MANIPULATING ROOT SYSTEMS

There is considerable evidence that root morphology and physiology influence water use of agricultural species and that there are opportunities to modify the root characteristics by both changing plants and altering management.

In the cereal belt of Western Australia, Sedgley *et al.* (1981) found nearly twice as much water drained from a subterranean clover pasture (*Trifolium subterranaeum*) than from a wheat crop and attributed the difference to greater rooting depth of wheat. Nulsen and Baxter (1982), working in the same region, measured *Ea* from a number of crops including barley, lupins and subterranean clover and found that *Ea* was greatest from barley and lupins. These crops have greater rooting depth than subterranean clover (R. A. Nulsen, pers. comm.). In the New England region of New South Wales, Begg (1959) found that *Phalaris aquatica* extracted more water from the soil than native grasses and dried the soil to a greater depth, a consequence of deeper roots.

Changes in soil management have been shown to influence root characteristics of wheat. Ellington (1982) at Rutherglen in northeast Victoria has shown that deep ripping increased the quantity of roots in the 0.40-0.70 m zone from 0.06 t ha^{-1} to 0.45 t ha^{-1}.

Late seeding, high rates of seed and high fertilizer application rates led to increased *Ea* by wheat at Wagga Wagga in southern New South Wales (Fischer & Kohn 1966a). Some of the increase was attributed to increased root density. Grain yield was shown to depend on the severity and timing of plant water stress and maximum yields did not necessarily correspond to maximum *Ea* (Fischer & Kohn 1966b). Greacen and Hignett (1976) report that low density of wheat roots restricted water use for wheat in South Australia, and yields suffered as a consequence.

There is a suggestion that root development can be manipulated by soil amelioration with gypsum in the wheat growing areas of Victoria. Experimental evidence for soils treated with gypsum shows that there is greater water use (Cooke & Willatt 1981), greater water use efficiency (unpublished data) and greater yields (Sims & Rooney 1965, Cooke & Willatt 1981) in such cases.

GROWTH PATTERNS

Lengthening the growing season has been suggested as one means of increasing water use by plants (Malcolm 1982) but there is little evidence to support this claim and there appears to be little scope to achieve this with annuals in Victoria. For example, the seeding date for wheat is largely controlled by the selection of the optimal date of flowering which depends on incidence of frost and factors relevant to water supply (Fischer 1979). When wheat is seeded early the date of flowering is brought forward to a period where the chance of frost is high. If wheat is forced to flower later to extend the growing season, the chance of the crop maturing during a dry period is increased. Dry soil conditions during autumn prevent the use of those cereal varieties suitable for early seeding and also prevent the adoption of management practices that allow early seeding. Further, the choice of seeding date is largely controlled by climatic conditions because seeding can be delayed due to the soil being too dry or too wet. Similarly the choice of subterranean clover varieties is largely based on the chance of seed set occurring prior to water stress in late spring (Wolfe & Southwood 1980). Species which mature later, may produce more dry matter in most years but in years when water stress occurs in early spring they fail to produce sufficient seed to guarantee their persistence.

THE POTENTIAL OF ALTERNATE CROPS AND PASTURES IN SALINITY PREVENTION

One species that has considerable potential as an alternative is lucerne, of which the cultivar 'Hunter River' has been traditionally grown. This is a spring and summer growing cultivar and low winter temperatures limit its growth in northern Victoria, even though water is used during that period. In an experiment in the Northern Irrigation Region (Steed, pers. comm.) it was found that lucerne used water at a rate at least equal to *Eo* during the winter period when not irrigated so that although growth was slow, the crop had the potential to

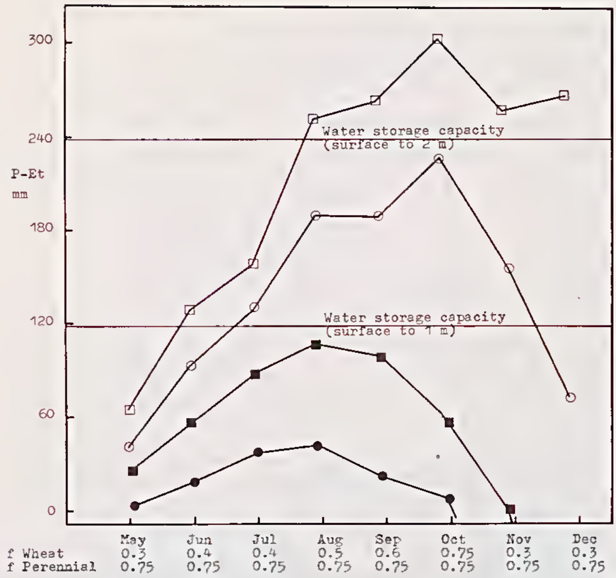

Fig. 1 — Cumulative difference between rainfall (P) and potential evaporation (Et) during the growing season for an average year (closed symbols) and 1973 (open symbols) for a perennial pasture (● ○) and wheat (■ □). Et = f * Eo where Eo is long term average pan evaporation, Tatura, and f is the ratio of Et to Eo which is presented at the base of figure. Also shown is the storage capacity ('Field capacity' less 'wilting point') for a typical duplex soil (0.12 mm/mm).

grow rapidly when air temperatures were more favourable. In this period roots extended to 1.5 m, which is one of the necessary requirements for improved water use. When temperatures increase in spring the lucerne will grow and produce harvestable yield and use water from the entire root zone. This zone is then available for water storage when the lucerne is removed or during a wet winter even if the lucerne has not been harvested. If 1.5 m of the profile is available for storage (Cooke & Willatt 1981) then the soil can accept some 150 mm of rainfall which is adequate for the high drainage component that occurs in very wet years.

Water use efficiency, the quantity of dry matter produced for each mm of water, of lucerne is greater in spring than summer in non-irrigated areas, when values of $Ea = 0.5\ Eo$ and $0.2\ Eo$ respectively (Snaydon 1972). Fischer (1979) reports similar values for wheat. Thus more efficient production occurs when lucerne uses water in spring than if water use is delayed to summer. This is an important concept because annuals, which use most water in the spring when water supply can be 0.3-0.5 *Eo*, may be more efficient than perennials which use water in summer when rainfall can be as low as 0.2 *Eo* or in the winter when temperature reduces water use efficiency.

It appears that there is potential for mixing pasture species (Wolfe & Southwood 1980) to optimise growth. Lucerne, Hunter River var., (winter dormant) and annual subterranean clover (winter active) can be combined so that pasture can actively grow in any season when water is available. The winter limitation to growth in most years is low temperature, which limits water use efficiency. Fig. 1 shows the accumulation of water in the soil, estimated from the difference between rainfall and *Et*, under average conditions and wet conditions (1973) for a wheat crop and a perennial pasture. This illustrates that a perennial pasture with higher *Et* accumulates less soil water and has a greater potential to store water. Another crop strategy would be to use lupins in the drier northern regions but, as early growth of lupins in Victoria is governed more by temperature than by water supply, they may not be suitable. If water is not available in late autumn (April-May), when temperatures are satisfactory, germination will not take place; when the soil is wet in June or July (early winter) temperatures are too cool for lupin growth (Willatt & Lindsay (in prep.).

PRACTICAL IMPLICATIONS

It is likely that changes in farm management which increase evapotranspiration would lead to substantial reduction of recharge to groundwater in northern Victoria. These changes would be to provide conditions for improved root development and function, and to introduce species with improved root characteristics. In some cases, however, increased evapotranspiration could be accompanied by reduced water use efficiency.

The use of lucerne with other plants or as a rotational component appears to have potential by providing a satisfactory pasture as well as utilising large quantities of water. The selection of the most suitable species, variety and management options will be largely influenced by soil and climatic factors and be controlled by economic considerations. There will be little progress towards the prevention of dryland salinity until detailed experimentation of water use is undertaken. This work must be undertaken in the field in areas representative of known groundwater intake areas.

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THE ROLE OF TREES IN DRYLAND SALINITY CONTROL

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Abstract: Tree planting is likely to play a part in control strategies for dryland salting, due to the high annual water use of trees relative to agricultural crops or pasture. Applications of tree planting include both recharge control and discharge control of salting. Efficient design of planting plans for recharge control requires identification of the areas in each catchment where groundwater recharge is most intense. Tree planting should be considered as the primary control measure in these areas, and should also be integrated with modified farming practices to minimise groundwater recharge over the remainder of the catchment. The location and density of planting needed for effective control of recharge will usually allow continued agricultural production within the planted area.

Establishment of trees within groundwater discharge areas is more difficult and is unlikely to achieve long term salinity control unless recharge control is simultaneously applied, when discharge control will hasten the reclamation of salted land. The location and density of planting required depend on the characteristics of the discharge area, and further research would be necessary to gain a full understanding of the application of tree planting in these areas.

Species selected for salinity control planting must be able to make good growth on the site to be planted, to transpire large quantities of water, and to provide other products or benefits as far as possible. Choice of species should be made on the basis of experience and local knowledge, supplemented by consideration of ecological requirements. The development of agroforestry systems which combine tree growing with conventional agricultural production without economic disbenefit will assist in the necessary introduction of large numbers of trees into farming areas.

Tree planting has repeatedly been suggested as a means of controlling salinity in Victoria and elsewhere (Morris *et al.* 1981, Greenwood 1978, Garland & Duff 1981, Anderson 1982). Although some of the suggested applications of trees are unlikely to be feasible for either physical or economic reasons, it is now apparent that successful control strategies for dryland salting will probably include tree planting in combination with agricultural and engineering measures. The purpose of this paper is to examine what part trees might play in such a combined strategy.

The potential of some tree species to control salting lies in their ability to use more water than crops or pastures on an annual basis, and to draw it from deeper in the soil profile. The primary features contributing to this effect are an evergreen perennial habit and an extensive root system; other features of importance in some species include leaf area, canopy structure and physiological factors such as the ability to continue transpiring at relatively low soil water potential. Some indigenous eucalypts are particularly well suited for salinity control planting, in addition to being naturally adapted to the Victorian climate. Some measured rates of transpiration for eucalypts and other species are listed in Table 1. An aspect of canopy structure worthy of special mention is the capacity of tree crowns to intercept incident rainfall. This may rival transpirational water use as a means by which trees limit the amount of water percolating into the soil, particularly in areas or at times of the year when rain falls predominantly as light showers. In addition to their water use, the possibility of salt uptake by trees has been considered by some as a means of lowering soil salt concentrations. The rapid growth, large stem volume and ability of some species to resprout from a cut stump have led to suggestions of a system of short-rotation coppiced eucalypts, with salt-laden stems and foliage being harvested and removed from the site every few years. Appealing as such a scheme may be, the calculations in Example 1 show that it is clearly not feasible.

There are two distinct approaches to tree planting for salinity control. The first and most important is planting in groundwater recharge areas to reduce the volume of water passing beyond the root zone to replenish groundwater reserves; the second approach is to establish trees in discharge areas with the intention of lowering raised water tables by drawing on the groundwater for transpiration. The remainder of this paper is concerned with the question of where, how much and what species to plant for effective salinity control by each of these approaches.

RECHARGE CONTROL

Some groundwater recharge is likely to occur over virtually the whole area of most Victorian catchments, at least in wet years (Dyson & Jenkin 1981). However, the volume of recharge per unit area may vary greatly in both time and space. The amount of rainfall and evaporation, land use or vegetation type, topography, soil, and geology of a catchment all influence the quantity of water which enters the soil at a given point and passes through the profile to join the groundwater. Naturally, the larger the catchment under consideration, the more variation will be displayed in each of these factors and the more variation can be expected in groundwater recharge. Even in small catchments however it should be possible to define zones of greater and lesser

TABLE 1
SOME ESTIMATES OF DAILY AND LONGER TERM WATER USE BY EUCALYPTS AND OTHER SPECIES

Species	*Water Use*	*Notes*
Eucalyptus occidentalis	558 mm over 5 months of summer	12 year old plan-plantation. (Stibbe 1975)
Eucalyptus species	Up to 3 mm day^{-1} during summer	2 years post germination. (Greenwood & Beresford 1979)
Eucalyptus camaldulensis	562 mm year^{-1}	(Karschon & Deth 1967)
Mature eucalypt forest	Up to 739 mm over 16 months	(Carbon *et al.* 1982)
Eucalyptus wandoo	1100 mm year^{-1}	Based on projected canopy area of scattered trees (Greenwood *et al.* 1981)
Pinus pinaster	Up to 738 mm over 16 months	(Carbon *et al.* 1982)
Pinus pinaster	Up to 610 mm year^{-1}	(Butcher 1977)
Pinus radiata	910 mm over 14 months (up to 3.3 mm day^{-1})	(Greenwood *et al.* 1981)
Pinus radiata	726 mm year^{-1}	(Holmes & Colville 1970b)
Atriplex vesicaria	Up to 1.3 mm day^{-1} during summer	(Greenwood & Beresford 1980)
Pasture	588 mm year^{-1}	(Holmes & Colville 1970a)
Pasture	540 mm year^{-1} (up to 4.1 mm day^{-1})	Greenwood *et al.* 1982)
Maize	Up to 6.5 mm day^{-1}	(Slabbers 1980; quoting other
Alfalfa	Up to 8.5 mm day^{-1}	workers)

recharge potential on the basis of slope and aspect. The importance of identifying areas of high groundwater recharge lies in the possibility of concentrating salinity control efforts in these areas. Methods are available for mapping recharge contours over large areas, based on indices such as soil moisture at depth, soluble ion content, earth resistivity or other measures of the degree of leaching. Such surveys are however expensive and at best it will be some years before extensive recharge data are available for the major salt-affected catchments of this state.

Rather than delay urgently-needed recharge control measures, it should be possible to identify major recharge areas where they exist by stratification of catchments on the basis of rainfall, vegetation, slope, aspect, and soil type, combined with existing knowledge of groundwater resources. Even a rough subjective classification along these lines should be adequate to point to the parts of a catchment where the hazard of recharge is greatest, thus allowing concentrated salinity control efforts to begin. The effects of non-uniform recharge on salinity control strategies are illustrated by the calculations in Example 2.

The distribution of groundwater recharge within a catchment may also vary from year to year. In some areas of low to moderate winter rainfall downward movement of water through the soil profile is limited by an impeding B horizon of low hydraulic conductivity. Groundwater recharge is therefore restricted, and in dry years could be confined to limited areas of shallow or coarse textured soils or bare fallowed ground. More commonly an impeding B horizon will tend to keep recharge uniform from year to year, as long as rainfall is sufficient to maintain the A horizon above field capacity through the winter. Rainfall in excess of the maximum drainage rate permitted by the impeding layer will then tend to be lost as surface runoff. This restriction of recharge is fortunate from a salinity control viewpoint, since extreme variation of recharge with time presents a problem for the design of control measures. For example, suppose it has been determined that salting in a given catchment is the result of an average increase in recharge of 20 mm per year since clearing of native forest. Strategies designed to reduce recharge by this amount may be ineffective if nine years of below average rainfall with zero excess recharge are followed by a tenth in which excess recharge is 200 mm.

The implications of recharge variability for land management in catchments subject to salting are clear. In the major or perennial recharge areas tree planting to maximise interception of rainfall and transpiration of soil water is an appropriate treatment: in many cases this will not conflict seriously with agricultural landuse since the recharge areas will tend to be on the shallow stony soils of hilltops and ridges (Jenkin 1981). In addition, agricultural practices in the rest of the catchment must be refined to allow more careful management of soil water storage. The aim should be to minimise the penetration of water beyond the maximum rooting depth of the crops or pastures grown; breeding of deeper rooted varieties of important species will help in the longer term. Thirdly, trees should be established as shelter belts, woodlots or ornamental plantings within the agricultural area, taking advantage of roadside verges and other unused land to remove some of the water stored at depth in the soil profile. By these measures the annual accession of water to the groundwater through major recharge areas will be halted or substantially reduced, and the extent of saturation of soils in the rest of the catchment minimised to provide reserve capacity for storage of water in periods of high rainfall.

Tree planting for regional recharge control is therefore of two types: 'primary' planting in the perennial recharge areas, and 'secondary' planting (combined with modified farming practices) throughout the cleared part of the catchment. The related questions of where and how much to plant in a given situation may be considered in terms of this classification. In general, the aim must be to plant where recharge takes place and to establish a large enough area of trees at sufficient density to eliminate this recharge.

The location and extent of primary planting are determined wholly by the size and location of identified perennial recharge areas: for effective control, trees must be planted within these areas and planting must extend over the whole area. The density of planting remains to be determined, and is of considerable importance as it affects the feasibility of combining tree establishment for recharge control with grazing, cropping or other landuse within recharge areas. To obtain the maximum benefit from interception of rainfall, trees must be planted closely enough to achieve more or less continuous crown cover over the whole recharge area. While this might be necessary in some limited areas of very high recharge, it is likely that the water-using capacity of tree species chosen for recharge control will usually be great enough to utilise all the infiltrating water in transpiration; interception is then a non-essential benefit of tree establishment, and tree spacing may be increased as long as continuous root cover over the whole recharge area is achieved.

It is important to appreciate that the planting density in recharge control areas need not be as high as that of the native forests which grew there before clearing. In the natural situation, the water use of individual trees is limited by water availability in the presence of competition from adjacent trees (Figure 1). As a result, total water use per unit area may be expected to be independent of tree density over a wide range. Furthermore, the use of selected high water-using species or varieties, and the application of management practices such as thinning and coppicing should allow an increase in the annual potential transpiration rate over that of the native forest. In any case, the aim of eliminating groundwater recharge within identified perennial recharge areas is an ideal which need not be wholly achieved: a complete return to pristine conditions of groundwater recharge, watertable level or stream salinity in farmed catchments is not necessary to overcome dryland salting and restore stream water qualities to an acceptable standard. The relation between potential tree water use and the proportion of a catchment retained under forest is examined further in Example 3.

The location and extent of secondary planting for reduction of ephemeral recharge over large cleared areas are strongly influenced by the availability of land and the willingness of landholders to establish trees as shelter belts, woodlots, ornamentals or for other purposes within prime agricultural areas. Tree establishment should be concentrated in those parts of a catchment where the risk of a substantial 'overflow' of soil water into the groundwater is greatest. The characteristics of such high-risk areas are similar to those of perennial recharge areas, including high effective rainfall, relatively coarse textured soils, low slopes and shallow groundwater.

Fig. 1 — Expected form of the relationship between tree density and water use per unit area for high (solid line) and low (broken line) levels of potential transpiration.

The density of this type of tree establishment will rarely be sufficient to remove all the water stored or penetrating below pasture and crop root zones. The aim should be to plant as many trees as possible, without reducing agricultural productivity. There are undoubtedly many opportunities for tree planting within this constraint on most Victorian farms, and on public land in agricultural districts. Possibilities include roadsides, easements, reserves, land too steep, stony or boggy for economic agricultural use, and around homesteads. To these may be added deliberate commitments of farm land for tree growing for a specific purpose, including shelter belts and woodlots producing firewood, round timbers, pulpwood or sawlogs. In every case, benefits will accrue to the landholder and the local community, not only through salinity control but by providing shade, shelter, landscape amelioration and wildlife habitat in addition to harvestable tree products.

DISCHARGE CONTROL

Efforts to overcome dryland salting have in the past been directed mainly at treatment of the affected area to re-establish vegetation, limit surface evaporation and promote leaching. Although discharge control measures such as these are a natural first approach, the greater importance of recharge control is now widely recognised (Williamson 1981, Jenkin 1981). The vegetative cover established by careful treatment of a salt seep is at best a fragile pasture which can survive only slight grazing and must be managed separately from adjacent land; leaching of salt seep soils is often hindered by a tendency of the soils to disperse and prevent infiltration as soon as fresh water is applied. In any case leaching without deep drainage or recharge control is likely to add to the problem by further raising the watertable below a seep.

Where salting is the result of a high regional watertable, localised controls will not be adequate in the long term: new outbreaks may occur outside the range of the control measures. The use of trees as 'biological pumps' for discharge control may even aggravate the problem in